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THE CHARACTERIZATION OF HEAVY WATER UPGRADER DEPOSITS

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Samples from the Pickering NGS moderator D_2O upgrader and the Bruce 'A' NGS heat transport D_2O upgrader have been analyzed for the identification of deposits plugging the distributors. The samples, including reboiler residues, Sulzer packing and distributor sections, were investigated by techniques such as optical microscopy, X-ray fluorescence and diffraction and Auger electron analysis. The deposits proved to be mainly well crystallized cuprous oxide, Cu_2O, together with smaller amounts of cupric oxide, CuO, and elemental copper. In addition surface contamination by carbon, nitrogen and sulphur containing species was identified on many Sulzer packing samples. It is proposed that organic amines and thiols, from the breakdown of ion-exchange resins, are responsible for the dissolution of copper on the packing. The mobilized copper is subsequently reprecipitated, mainly as Cu_2O, in the distributors.

INTRODUCTION

Heavy-water upgraders are operated at the Pickering and Bruce nuclear generating stations to maintain the isotopic purity of the heavy water used in the moderator and heat transport systems. The upgraders are multiple section distillation columns with each section consisting of a distributor followed by layers of a surface activated phosphor-bronze mesh known as Sulzer packing.

After an initial period of satisfactory operation the upgraders eventually exhibit a loss of upgrading capacity and must be taken out of service for the removal of deposits which cause inadequate flow through the distributors.

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The nature of these deposits is the subject of the present investigation. Samples from a Pickering moderator heavy water upgrader and a Bruce 'A' heat transport heavy water upgrader were submitted to Ontario Hydro Research (OHR) in July 1988 and were analyzed by a variety of techniques. The results of these analyses are presented in this report and the mode of formation of the deposits is also briefly discussed.

1.0 DESCRIPTION OF SAMPLES AND ANALYTICAL PROCEDURES

Of the heavy water upgrader samples submitted to OHR the following have been investigated in detail:

Pickering Moderator D_2O Upgrader Samples

1. Reboiler residue
2. Sulzer packing from sections 18, 19 and 39.

Bruce 'A' Heat Transport D_2O Upgrader Samples

1. Reboiler residue
2. Sulzer packing from sections 1 and 32
3. A stainless steel strainer basket from section 6
4. A distributor from section 20

All samples were first checked for radioactivity and then photographed at low and medium magnifications to document the location, colours and structural features of the deposits. When more than a milligram of loose material was available it was subjected to energy dispersive X-ray fluorescence analysis (EDXA) for the determination of elements with atomic number ≥11 and X-ray diffraction (XRD) for the identification of crystalline phases. Water leachable anions such as sulphate, chloride and nitrate were also determined in these samples by ion-chromatography.

The microcharacterization of all samples was carried out in a JAMP-10 Scanning Auger Microprobe (SAM). This instrument not only records high resolution secondary electron images of a sample, as in a conventional scanning electron microscope, but also measures the energy spectrum of Auger electrons permitting the quantitative determination of all elements present except hydrogen.

2.0 RESULTS

2.1 Sample #1: A Reboiler Residue from the Pickering NGS Moderator D_2O Upgrader

The sample of Pickering NGS reboiler residue, consisting of about 10 g of a brownish-black powder, was found to be quite radioactive and was therefore analyzed with an Ortec 7050 nuclear spectrometry system for the determination of gamma active radionuclides. In addition 1 g of the sample was agitated in 10 mL of water, the suspension passed through a 0.45 μm filter, and the filtrate analyzed by liquid scintillation counting for the determination of tritium (H-3). The results of these analyzes are reported in Table 2.1.

Table 2.1

Specific Activity of Radionuclides Determined in a Pickering NGS Reboiler Residue

Radionuclide	Specific Activity (nCi/g)
H-3	160.0 ± 3.0
Mn-54	0.7 ± 0.2
Co-60	31.0 ± 0.6
Zr-95	0.6 ± 0.3
Nb-95	1.6 ± 0.2
Ru-106	3.9 ± 0.9
Sb-125	2.3 ± 0.4
Cs-137	0.4 ± 0.2
Gd-153	10.3 ± 0.9

The radionuclides detected in this sample are the activation or fission products normally found in moderator D_2O. (Gd-153 stems from the activation of gadolinium added to the moderator for guaranteed shutdown).

The results of energy dispersive X-ray analysis (EDXA) of the reboiler residue are given in Table 2.2. (The values quoted are normalized to 100% for the elements detected; it is probable that most of the elements are present as their oxides).

Table 2.2

Elements Determined in a Pickering NGS Reboiler Residue by EDXA

Element	Concentration (wt %)
Al	0.5 ± 0.1
Si	1.2 ± 0.2
P	0.2 ± 0.1
S	0.4 ± 0.1
Ca	2.3 ± 0.4
Mn	0.02 ± 0.01
Fe	0.15 ± 0.03
Ni	0.10 ± 0.04
Cu	94.8 ± 0.5
Zn	0.14 ± 0.04
Sn	0.2 ± 0.1

X-ray diffraction of the reboiler residue showed the presence of both cuprous, Cu_2O, and cupric, CuO, oxides in the approximate ratio of 5:1.

Examination of the reboiler residue in an Auger microprobe showed agglomerates of particulate material with individual particles typically less than 2 μm in diameter. Although the composition of the material varied from particle to particle an average of 86 wt% copper, 12 wt% oxygen and 2 wt% carbon was found; traces (~1 wt%) of nitrogen and sulphur were also occasionally detected in association with the carbon.

Ion-chromatography showed that 25μg of sulphate ion could be leached from 1 g of the reboiler residue.

2.2 Sample #2: Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader

Sulzer packing samples from section 39 of the Pickering NGS Moderator D_2O upgrader were generally dull-black in appearance but also exhibited localized areas with a marked yellowish-orange colour. Figs 2.1 and 2.2 are optical micrographs of areas of packing showing these types of coloration.

Figure 2.1 Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader (Magnification 44x)

Figure 2.2 Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader (Magnification 44x)

Figures 2.3 and 2.4 are scanning electron micrograph of black areas of the packing recorded in the secondary electron imaging mode of an Auger microprobe. Secondary electron image contrast is due to variations in the emissive power across a sample surface and is, of course, quite different to optical image contrast. Thus conducting surfaces appear as grey or black areas while non-conducting surfaces are white or shiny from enhanced electron emission.

With these facts in mind it is clear that Fig 2.3 shows the presence of a non-conducting deposit over localized areas of the black coloured packing. Auger electron analysis of points within this deposit showed mainly carbon suggesting either graphite or an organic material. However, carbon was also found at significant levels at points not on a visible deposit indicating that carbon deposition has occurred throughout the black coloured area of the packing.

Figures 2.5 and 2.6 are scanning electron micrographs of yellow coloured areas of packing 39. A loosely adherent, partially exfoliated, scale is clearly visible which was shown by Auger electron analysis to be highly enriched in tin. Thus, while the bronze substrate of the packing is known to contain 5 wt% tin, the scale showed tin concentrations as high as 80 wt%. It is suspected that the copper oxide originally present on the packing has been lost in this area by some type of corrosive attack. Bronzes oxidize by forming an external scale consisting mainly of Cu_2O with an internal, tin-rich, zone; it is evidently this zone that has been exposed by loss of the outer oxide. Auger electron analysis at randomly chosen points within the yellow coloured areas of packing also detected carbon (major), sulphur (minor), nitrogen (minor) and iron (trace); these elements are probably constituents of insoluble residues left by the corrosive agent(s).

2.3 Sample #3: Sulzer Packing from Section 19 of the Pickering NGS Moderator D_2O Upgrader

Inspection of the packing sample from section 19 of the Pickering moderator upgrader showed that it has a loose weave and is therefore of the type designated as BX as opposed to the tight weave, or CY type, found in the other packing samples submitted to Research.

The section 19 sample was generally dull-black in appearance although shiny areas were visible on protruding surfaces of the packing viewed at low magnification as shown in Fig 2.7; this suggests that the copper oxide coating has been lost from these areas by physical contact with other surfaces.

Figure 2.8 is an electron micrograph of the packing showing the original oxide coating as well as a smooth area with the oxide missing. Auger electron analysis of oxide coated areas of the packing showed the presence of up to 12 wt% carbon, 1 wt% nitrogen and 2 wt% sulphur in addition to the expected copper and oxygen. Analysis of smooth areas gave essentially the same result except for the inclusion of iron at concentrations as high as 15 wt%.

Figure 2.3 Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader (Magnification 100x)

Figure 2.4 Sulzer Packing from Section 39 of the Pickering NGS Moderator D2O Upgrader (Magnification 1000x)

Figure 2.5 Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader (Magnification 450x)

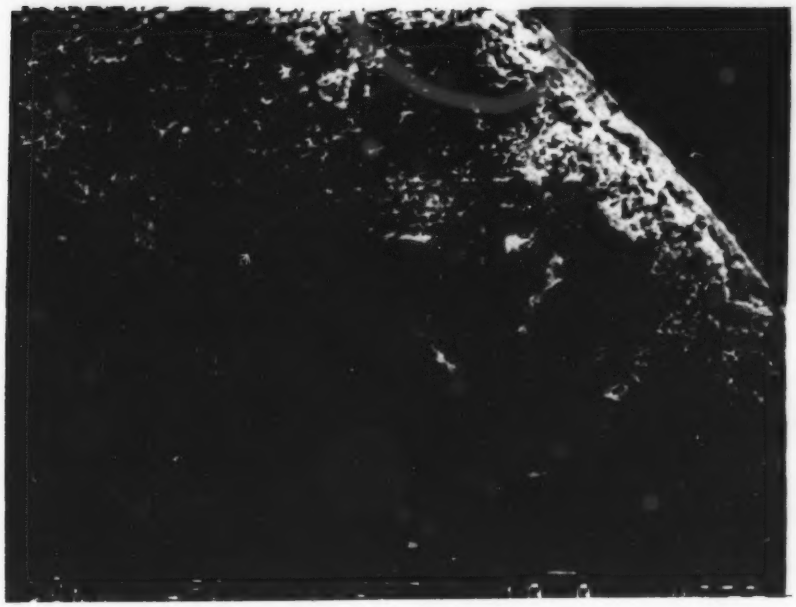


Figure 2.6 Sulzer Packing from Section 39 of the Pickering NGS Moderator D_2O Upgrader (Magnification 450x)

Figure 2.7 Sulzer Packing from Section 19 of the Pickering NGS Moderator D_2O Upgrader (Magnification 35x)

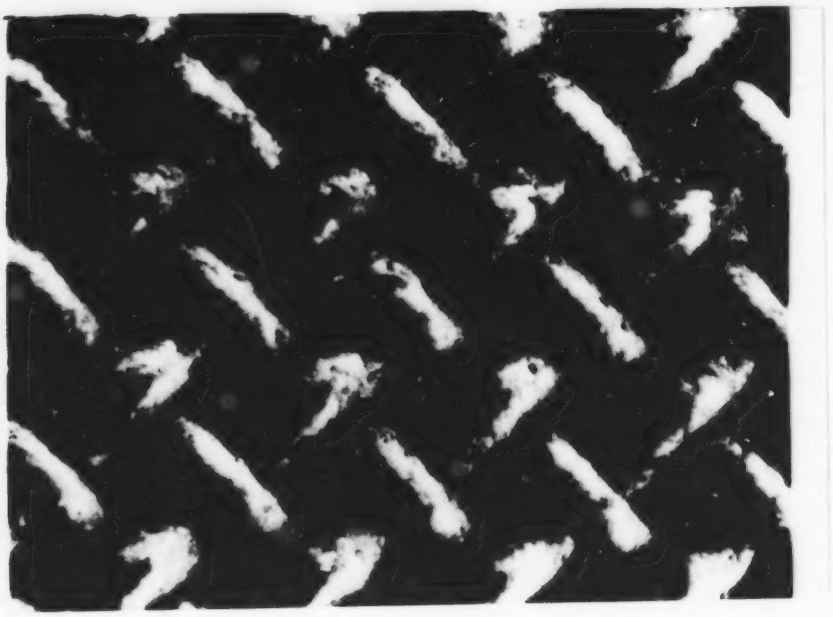
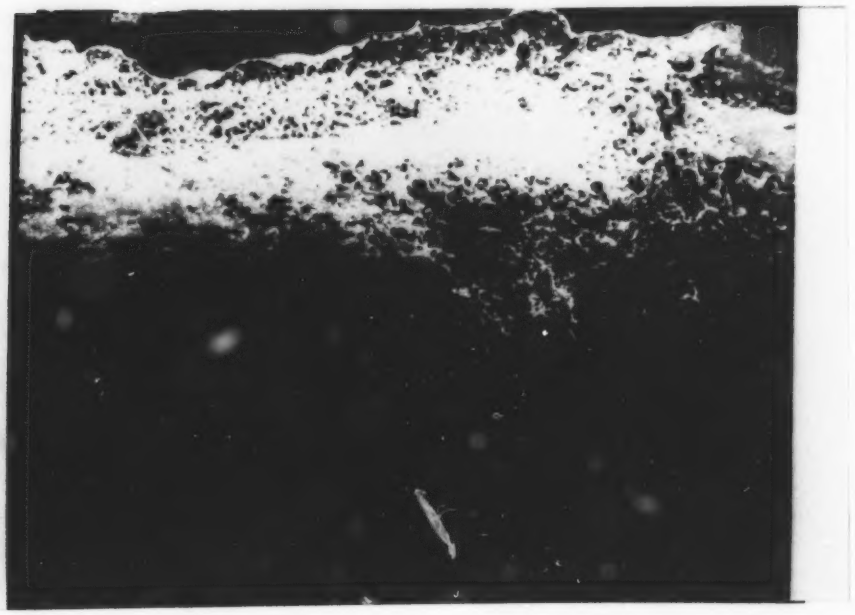


Figure 2.8 Sulzer Packing from Section 19 of the Pickering NGS Moderator D_2O Upgrader (Magnification 300x)



In order to determine the extent of coverage of the copper oxide by elements such as carbon and iron, the packing was sputtered with a 3 keV argon-ion beam for periods between 5 and 50 minutes. The sputtering rate was estimated to be about 25 nm/min based on previous measurements. It was found that the elements carbon, nitrogen, sulphur and iron were only slightly reduced in concentration showing that these elements were present in a layer at least 1 μm thick.

2.4 Sample #4: Sulzer Packing from Section 18 of the Pickering NGS Moderator D_2O Upgrader

Figures 2.9 and 2.10 are low magnification optical and electron micrographs, respectively, of the same area of packing from section 18 of the Pickering NGS moderator D_2O upgrader. Heavy deposition of a reddish-brown material is clearly visible; higher magnification, as in Figs 2.11 and 2.12, shows that the deposit is in fact crystalline with mainly cubic crystals up to 20 μm in diameter.

Auger electron analysis of this area of packing showed the crystals to consist of copper and oxygen in the atomic ratio $(2.0 \pm 0.1):1$. Copper is known to form two stable oxides: red, cubic, cuprous oxide Cu_2O, and black, monoclinic, cupric oxide CuO. Hence it may be concluded that crystalline cuprous oxide has deposited on the surface of section 18 packing.

Contamination of both the crystals and the underlying packing by carbon, nitrogen and sulphur was very extensive with the nitrogen concentration being consistently 8% of the carbon. Localized and minor contamination by iron and tin was also observed.

2.5 Sample #5: A Reboiler Residue from the Bruce NGS 'A' Heat Transport D_2O Upgrader

A few milligrams of a reddish-brown reboiler residue from the Bruce NGS 'A' heat transport heavy water upgrader was made available to Research for analysis. The residue was collected in 1986 and was found to have no radionuclides present with activities greater than 1nCi at the time of analysis.

The results of energy dispersive X-ray analysis (EDXA) of the reboiler residue are given in Table 2.3. (The values reported are normalized to 100%; it is probable that most of the elements are present as their oxides).

X-ray diffraction of the reboiler residue showed the presence of both cuprous, Cu_2O, and cupric, CuO, oxides in the approximate ratio of 10:1.

Figure 2.9 Sulzer Packing from Section 18 of the Pickering NGS Moderator D_2O Upgrader (Magnification 44x)

Figure 2.10 Sulzer Packing from Section 18 of the Pickering NGS Moderator D_2O Upgrader (Magnification 45x)

Figure 2.11 Sulzer Packing from Section 18 of the Pickering NGS Moderator D_2O Upgrader (Magnification 200x)

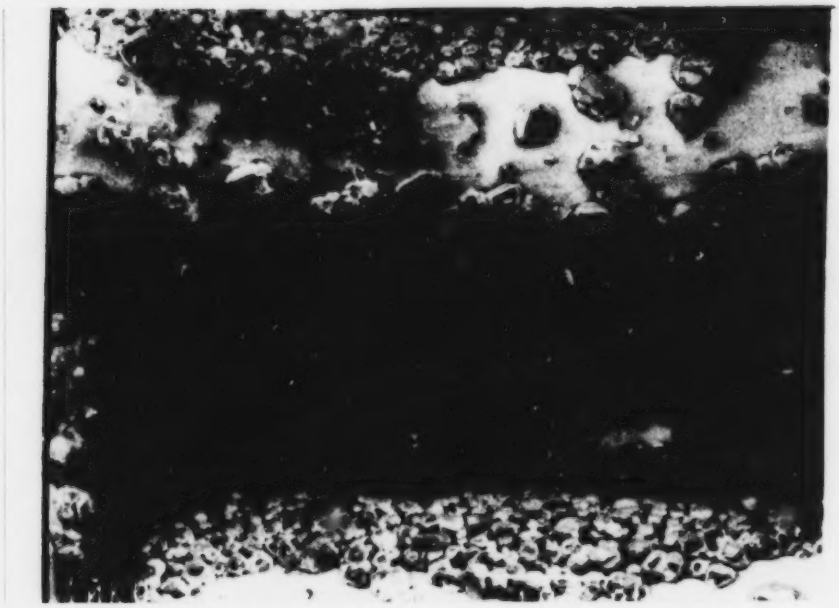


Figure 2.12 Sulzer Packing from Section 18 of Pickering NGS Moderator D_2O Upgrader (Magnification 1000x)

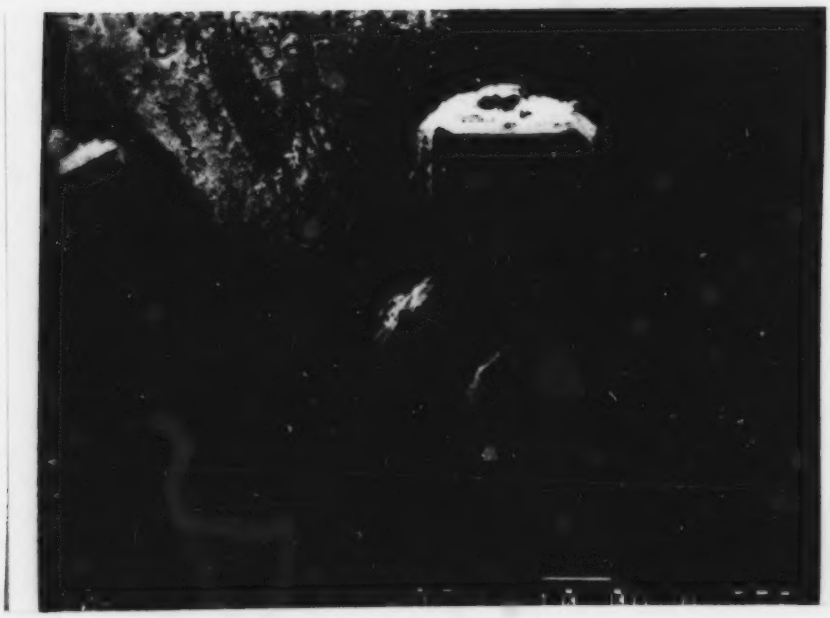


Table 2.3

Elements Determined in a Bruce NGS 'A' Reboiler Residue by EDXA

Element	Concentration (wt%)
Al	0.4 ± 0.1
Si	0.9 ± 0.2
P	0.4 ± 0.2
S	0.2 ± 0.1
Ca	0.2 ± 0.1
Cr	0.6 ± 0.2
Fe	1.3 ± 0.4
Ni	0.2 ± 0.1
Cu	95.0 ± 0.5
Zn	0.2 ± 0.1
Sn	0.6 ± 0.2

2.6 Sample #6: Sulzer Packing from Section 32 of the Bruce NGS 'A' Heat Transport D_2O Upgrader

The sample of Sulzer packing from section 32 of the Bruce NGS 'A' heat transport heavy water upgrader showed extensive yellowish coloured areas as well as localized regions exhibiting a pale blue "patina". Under low magnification, as in Figure 2.13, the blue patina is seen as a scale which readily spalls off under flexure of the packing.

Auger electron analysis of the yellowish areas showed copper and oxygen in association with tin while the blue patina proved to be tin and oxygen with only small (<10 wt%) amounts of copper. The tin-to-oxygen atomic abundance ratio was invariably close to 1:1 suggesting that the tin is present as stannous, SnO, rather than stannic, SnO_2, oxide. (The origin of a tin-rich layer near the surface of a corroding bronze was previously discussed in Section 2.2 in connection with packing samples from Pickering NGS).

As shown in Figure 2.14, crystalline deposits were found on some areas of the section 32 packing. Auger electron analysis showed the crystals to be Cu_2O but carbon (major) and sulphur (minor) were also detected both on and off the crystals.

Figure 2.13 Sulzer Packing from Section 32 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 44x)

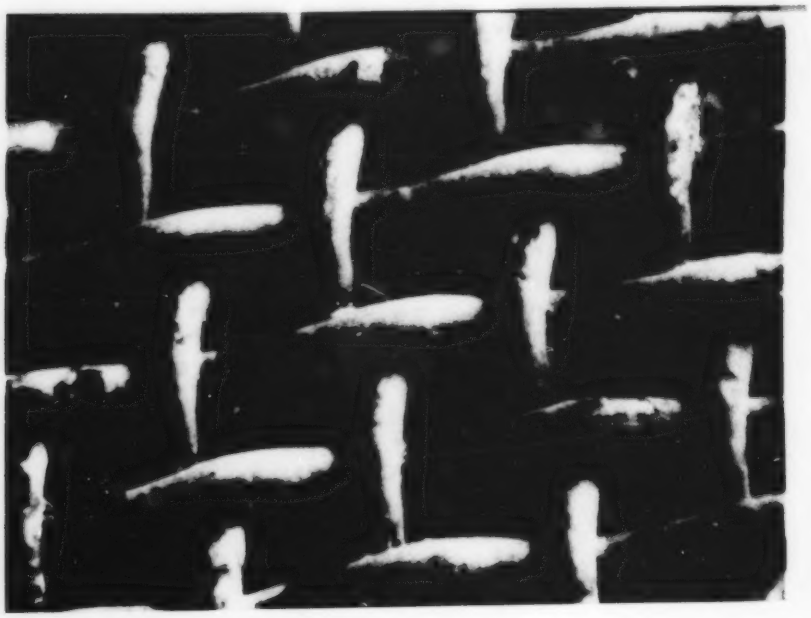


Figure 2.14 Sulzer Packing from Section 32 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1000x)

2.7 Sample #7: Sulzer Packing from Section 1 of the Bruce NGS 'A' Heat Transport D_2O Upgrader

The packing from section 1 of the Bruce NGS 'A' heat transport upgrader looked superficially like new packing. However, even at low magnification, as in Figure 2.15, the occurrence of a coarse particulate deposit on many areas of the packing was evident. Auger electron analysis of the deposited particles showed the presence of elements such as silicon, calcium, potassium, and aluminum. Ca/K/Al silicates are a major component of common dusts originating from soil, concrete, etc. It is probable that dust particles were introduced to the upgrader during construction and have subsequently been washed down the distillation tower during operation forming a detritus in the lowest section of the tower.

Auger electron analysis of the section 1 packing at locations not associated with deposited particles (see Figure 2.16) showed, as expected, CuO but variable levels of contamination from carbon (major) and sulphur, nitrogen and iron (minor) were also observed.

2.8 Sample #8: A Stainless Steel Strainer Basket from Section 6 of the Bruce NGS 'A' Heat Transport D_2O Upgrader

Visual inspection of the strainer basket from section 6 of the Bruce NGS 'A' heat transport heavy water upgrader showed a dark reddish-purple stain extending over most of the stainless steel mesh which forms the base of the basket. Figure 2.17 shows the stained area at low magnification while Figure 2.18 is a scanning electron micrograph of the same area at somewhat higher magnification. Very heavy deposition of a material coloured from red to brown or black is clearly visible.

Auger electron analysis of the few areas of the steel mesh that were free of deposit showed iron and chromium from the base metal together with carbon and sulphur surface contamination. The deposit itself proved to be pure copper oxide with almost no detectable contamination from any other species.

Figures 2.19 and 2.20 are scanning electron micrographs of the deposit taken at high magnification. The occurrence of fine needle-like particles together with clusters of cubic crystals, the individual cubes being up to 10 μm across, is noteworthy. It was possible to position the electron beam on individual particles or micron-sized spots to look for local variations in stoichiometry. It was found that the fine needles exhibit a copper-to-oxygen atomic abundance ratio close to 1:1, indicative of cupric oxide (CuO), while the cubic crystals gave a ratio of 2:1, indicative of cuprous oxide (Cu_2O).

Figure 2.15 Sulzer Packing from Section 1 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 44x)

Figure 2.16 Sulzer Packing from Section 1 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 450x)

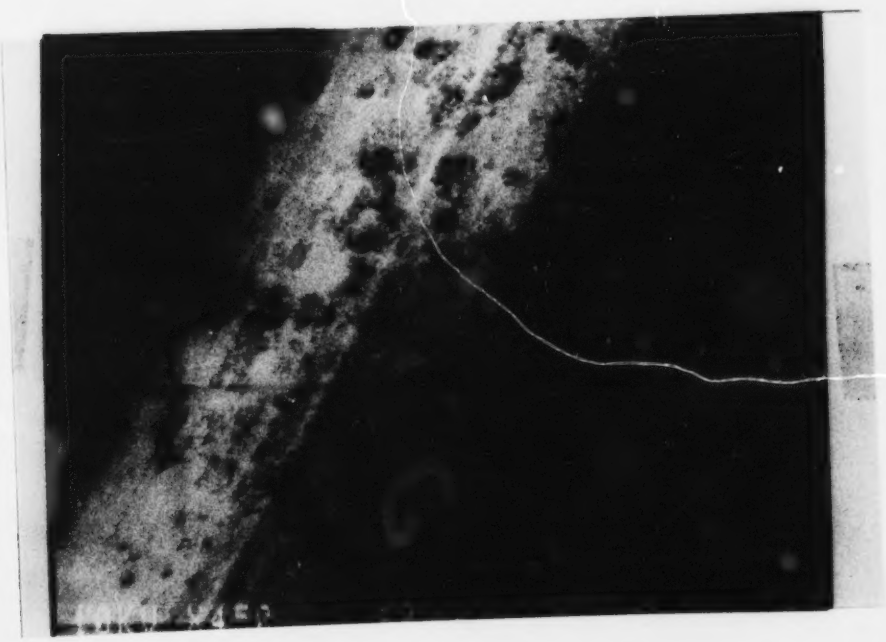


Figure 2.17 A Strainer Basket from Section 6 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 28x)

Figure 2.18 A Strainer Basket from Section 6 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 100x)

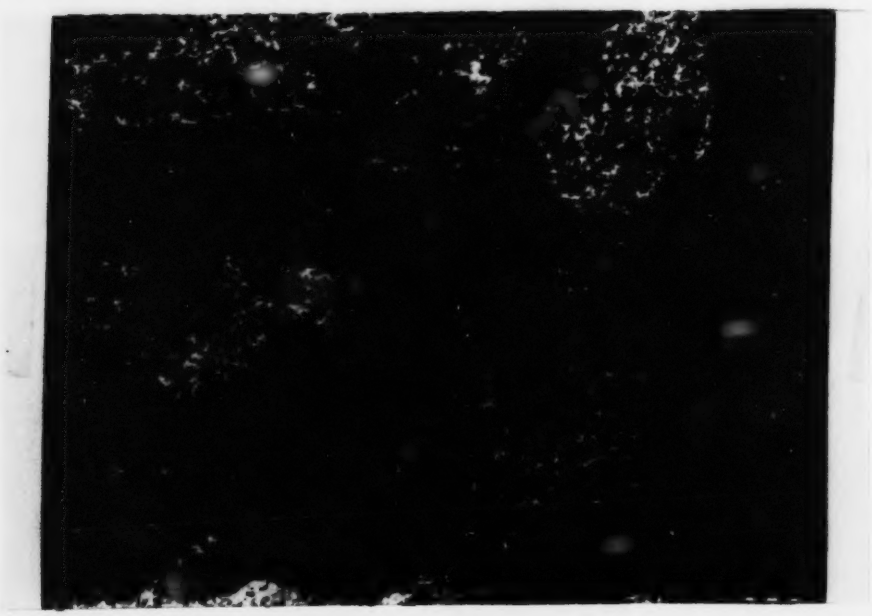
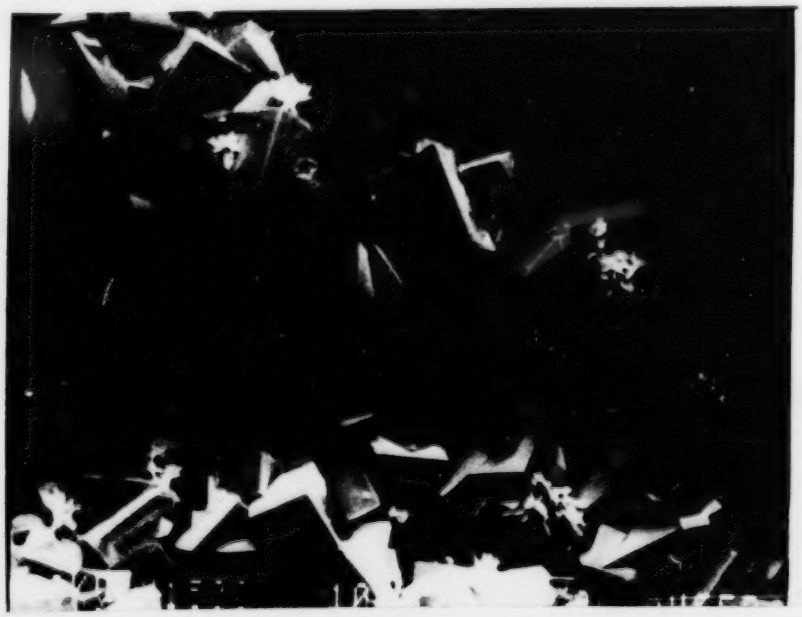


Figure 2.19 Deposit on a Strainer Basket from Section 6 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 700x)

Figure 2.20 Deposit on a Strainer Basket from Section 6 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1500x)



2.9 Sample #9: A Distributor from Section 20 of the Bruce NGS 'A' Heat Transport D_2O Upgrader

The distributor sent to Research from the Bruce NGS 'A' heat transport heavy water upgrader had no external deposits but was clean and shiny in appearance. However a close examination of the distributor holes revealed that a reddish-brown deposit had, in fact, formed on the inner surface of the tube (see Figures 2.21 and 2.22). By sectioning a distributor tube it was found that the deposit was concentrated at practically every distributor hole in the form of a small, flat "button" of material surrounded by a dark-brown or black ring (Figure 2.23). It was also found that the buttons could be removed with a scalpel and are remarkably similar in size and weight from hole-to-hole. Thus measurements on six buttons gave the following results:

An average diameter of 0.27 ± 0.02 cm
An average height of 0.033 ± 0.003 cm
An average mass of 3.58 ± 0.07 mg

(N.B. The corresponding distributor hole diameters averaged 0.14 ± 0.02 cm so that the deposit was approximately twice as wide as the hole).

The outer surface of a button, i.e. the surface shown in Figure 2.23, is composed of a highly compacted, fine grained, material which is frequently covered with small black spots (See Figure 2.24). By comparison, the surface of a button in contact with a distributor was found after removal from the tube to consist of a porous, loosely compacted, material (see Figure 2.30).

Figures 2.25 and 2.26 are scanning electron micrographs of typical areas on the outer surface of a distributor button deposit. These micrographs show that the surface actually consists of closely packed cubic crystals lightly decorated with clusters of needle-like particles. Auger electron analysis confirmed that the cubic crystals are Cu_2O and the needle-like particles are CuO. In Figure 2.25 the CuO needles are more abundant than in Figure 2.26; in the former case the Cu_2O crystals are also, on average, smaller (2-3 μm) than in the latter case (3-4 μm).

It proved possible to correlate the colour of a particular area on a button with the relative abundance of Cu_2O and CuO. The red areas were found to be rich in Cu_2O while the dark brown areas contained more CuO. In keeping with these trends, the previously mentioned black spots shown in Figure 2.24 were shown by Auger electron analysis to be very pure CuO.

Figures 2.27 and 2.28 are scanning electron micrographs of typical areas on the inner surface of a distributor button deposit, (i.e. the surface in contact with the distributor). As with the outer surface of the deposit both cubic crystals and clusters of needles are visible but generally in very loosely packed formations. Large voids are particularly abundant in Figure 2.28 indicative of a highly porous material. Auger electron analysis confirmed the presence of CuO and Cu_2O but elemental copper was also found in areas near the centre of the button. The presence of up to 50% of elemental

Figure 2.21 A Distributor from Section 20 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 28x)

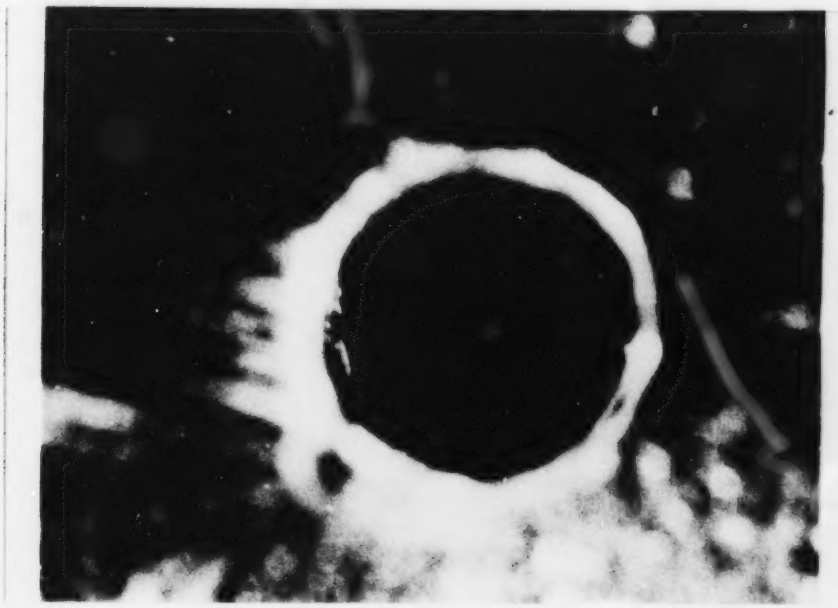


Figure 2.22 A Distributor from Section 20 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 28x)

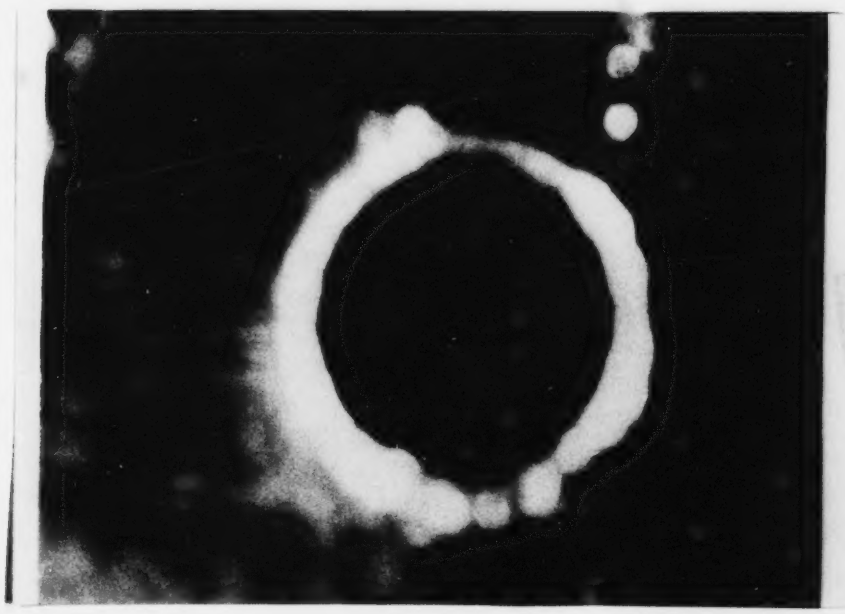


Figure 2.23 A Distributor from Section 20 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 2x)

Figure 2.24 A Distributor 'Button' Deposit from Section 20 of the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 28x)

Figure 2.25 Outer Surface of a Deposit on the Distributor from the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1000x)

Figure 2.26 Outer Surface of a Deposit on the Distributor from the Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1000x)

Figure 2.27 Inner Surface of a Deposit on the Distributor from Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1000x)

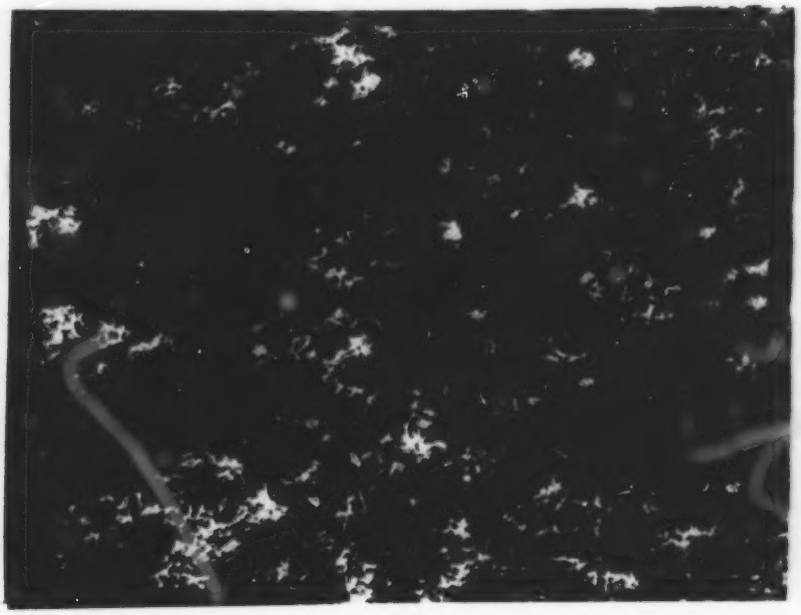
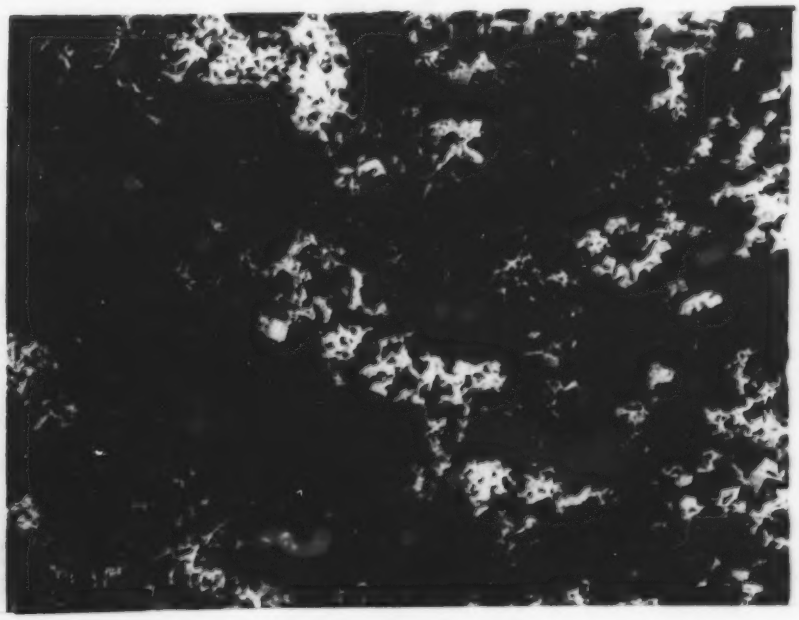


Figure 2.28 Inner Surface of a Deposit on the Distributor from Bruce NGS 'A' Heat Transport D_2O Upgrader (Magnification 1000x)



copper was also confirmed by X-ray diffraction analysis of material removed from the centre of a button. A copper-rich deposit is shown in Figure 2.29 where it occurs in association with cubic crystals of Cu_2O.

Variations in colour across the inner surface of a button signify an unusual concentric distribution to the copper and copper oxides. Thus inspection of the colours in Figure 2.30 shows that at the centre of the button, reddish-brown Cu_2O is most abundant. Similarly elemental copper has deposited in an intermediate, yellow-coloured zone, while dark-brown CuO is concentrated at the periphery.

The deposition of elemental copper in a ring around a distributor hole is also well illustrated by Figure 2.31. An outer ring of dark brown CuO is also clearly visible extending about 3 mm from the hole centre. (N.B. When in place, the button deposit extends less than 1.5 mm beyond the edge of the distributor hole).

At distances greater than 4 mm from the centre of a distributor hole crystalline deposits of Cu_2O were observed in conjunction with sparse deposits of needle-like CuO. As Figure 2.32 shows, the Cu_2O crystals are concentrated in cracks and crevices on the surface of the distributor tube. Traces of elemental copper were detected at the bottom of these crevices by Auger electron analysis.

3.0 DISCUSSION

Although a variety of samples from different upgrades have been investigated in this report many similarities are readily apparent from one result to another. It is therefore possible to make a number of generalizations concerning the nature of the upgrader deposits and dispense with a detailed consideration of every sample.

The majority of upgrader deposits are essentially pure oxides of copper and/or elemental copper and occur in regions normally free from copper. It may then be inferred that a process involving copper oxide dissolution followed by copper redeposition underlies deposit formation. It further follows that the plugging of the upgrader distributors is primarily caused by corrosion of the Sulzer packing.

The alternative mechanism of physical erosion of copper oxide particles from the packing is probably only of secondary importance for a number of reasons. Firstly X-ray diffraction analysis of unused Sulzer packing shows that it is coated with CuO, not Cu_2O; only about 10 wt% of Cu_2O could be detected in material scrapped off new packing. In addition the CuO coating is in the form of needle-like particles only a few μm across. Thus, the formation of large cubic crystals of Cu_2O implies that CuO particles set loose by erosion have undergone the transformation $Cu^{2+} \rightarrow Cu^{+}$, a process which, in itself, requires that CuO enters into solution. While it is probable that some physical erosion of the packing coating does occur, the occurrence of carbon, nitrogen

Figure 2.29 A Copper-rich Area on the Inner Surface of a Bruce NGS 'A' Distributor 'Button' Deposit (Magnification 1000x)

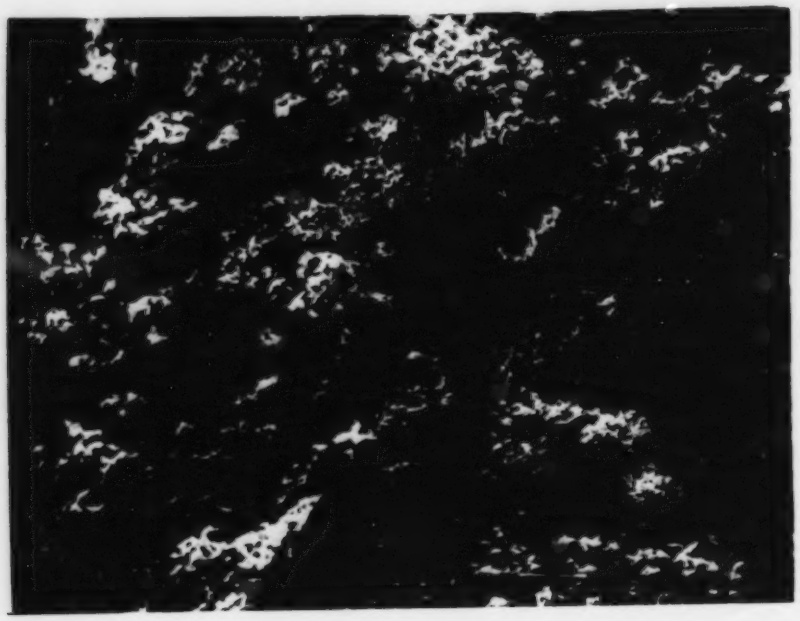


Figure 2.30 Inner Surface of a Bruce NGS 'A' Distributor 'Button' Deposit (Magnification 28x)

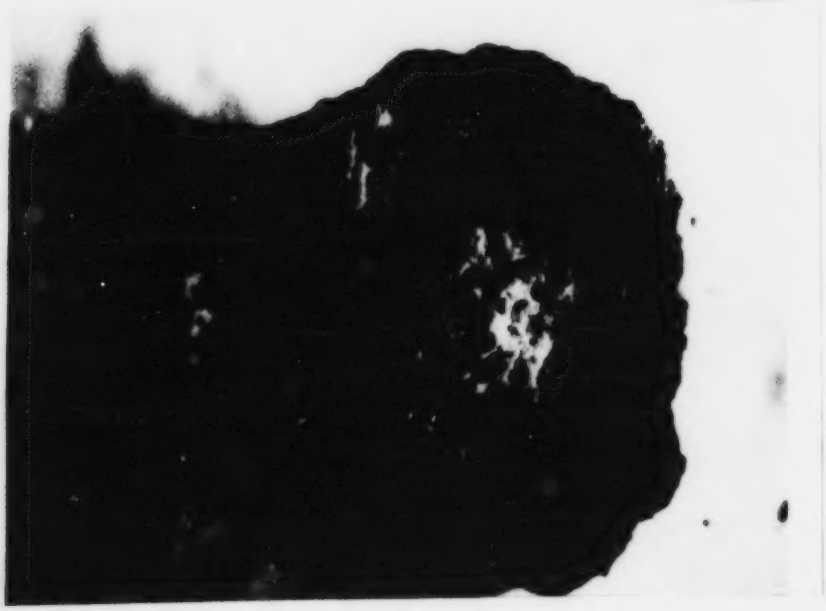


Figure 2.31 Distributor Hole Showing Residual Deposits After Removal of the 'Button' Deposit (Magnification 28x)

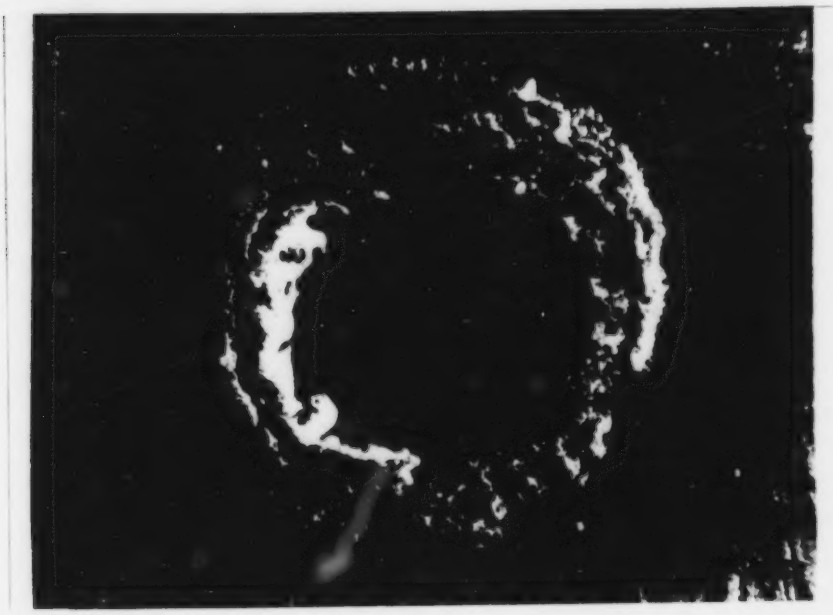


Figure 2.32 Deposits on the Inside Surface of a Distributor Tube Well Away from a Hole (Magnification 1000x)

and sulphur-rich deposits on used packing samples points to chemical attack at the surface of the packing as the principal process responsible for copper transport.

The identity of the corrosive agents causing the dissolution of copper from the Sulzer packing remains uncertain. Auger electron analysis, which provides only elemental information, shows that carbon, nitrogen and sulphur are ubiquitous in the heavily corroded areas of the packing. The high carbon levels measured suggest the presence of organic species; if these are nitrogen and sulphur compounds then amines and thiols are implicated. Species of this type are known breakdown products of the ion-exchange resins used in the heavy water upgrader purification circuits. Furthermore, amines and thiols are reducing agents which favour the formation of cuprous oxide or elemental copper over cupric oxide.

At present these ideas remain only speculative and lack experimental proof. A new program of investigations is now underway to carry out detailed chemical analyses of moderator and heat transport heavy water samples from Pickering and Bruce NGS. These studies, which will be reported elsewhere, are aimed at identifying the potentially corrosive agents present in the heavy water in the upgrader circuits. It is hoped that remedial measures may then be implemented to limit the formation of deposits in the upgrader distributors.

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